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MEMORANDUM REPORT No. 1109

OCTOBER 1957

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Penetration Of An Experimental .22 Cal. Bullet In Gelatin (U)

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JAMES W. CARROLL

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BALLISTIC RESEARCH LABORATORIES

ABERDEEN PROVING GROUND, MARYLAND

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PENETRATION OF AN EXPERIMENTAL .22 CAL. BULLET IN GELATIN (U)

Dennis J. Dunn

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Department of the Army Project No. 492-310-01
Ordnance Research and Development Project No. TB3-0114

ABERDEEN PROVING GROUND, MARYLAND

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BALLISTIC RESEARCH LABORATORIES

MEMORANDUM REPORT NO. 1109

DJDunn/JWCarroll/mmv
Aberdeen Proving Ground, Md.
October 1957

PENETRATION OF AN EXPERIMENTAL .22 CAL. BULLET IN GELATIN (U)

ABSTRACT

An experimental .22 cal. bullet was shot into a gelatin target at simulated ranges of 75, 250 and 450 yards. Whether or not the bullet shattered after impact was observed. Measurements were made of the distance from the impacted face to the center of the maximum temporary cavity, the volume of the maximum temporary cavity, and the length of the longest crack perpendicular to the trajectory in the gelatin. The effect of the bullet's spin rate and yaw angle at impact on the distance to the center of the maximum temporary cavity was determined.

INTRODUCTION

Animal tissue damage caused by a bullet which yaws considerably or tumbles is observed to be much greater than the damage caused by a non-tumbling bullet.[1,2*] Although conventional bullets are unstable in a dense medium[3], some can still pass completely through goat targets without attaining large angles of yaw. To obtain large yaws in dense media, Kent's[3] theory implies that the bullet should be designed so the value of $K_m \rho d^3/B$ is large. K_m is the overturning moment coefficient; ρ is the density of the target material; d is the diameter of the bullet; and B is the transverse moment of inertia of the bullet about an axis through the center of gravity. Thus, at a given depth of penetration, the yaw will be largest for the bullet having the largest value of $K_m \rho d^3/B$.** For two bullets which have the same shape but are unequal in size, B is proportional to d^5, K_m is constant and it follows that the small caliber bullet should yaw more than the large caliber bullet in equal penetrations.

An experimental bullet having a smaller diameter (.22 cal.) than the basic .30 cal. bullet has been designed [4] by these Laboratories in cooperation with the Frankford Arsenal. Tests of the experimental bullet were made by shooting it into a gelatin target. The growth of bullet yaw in the gelatin was indicated by measuring the distance from the impacted face of the target to the center of the maximum temporary cavity (an inverse relation). The effect of initial yaw angle and spin rate on the distance to the center of the maximum temporary cavity was experimentally determined. Measurements associated with the damage caused by the bullet were made; these consisted of the maximum temporary cavity volume and the length of the longest crack. Gross deformation of the bullet was noted. In the present paper the tests of the new bullet in gelatin are reported.

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*Superscripts refer to references.

**It is tacitly assumed that the yaw angle at impact is constant.

DESCRIPTION OF BULLET AND TARGET

The .22 Cal. bullet is described below:

diameter = .224 inch

length = .710 inch = 3.17 cal.

weight = 50 grains

filler = Pb (lead)

jacket = Cu (copper)

ogive form = tangent

ogive radius = 6 calibers

boattail = none

g x moment of inertia, axial = .262 grain - inch^2

g x moment of inertia, transverse through c.g. = 1.56 grain-inch^2

where g is the acceleration due to gravity.

distance from base to c.g. = 1.16 caliber

Estimated* value of the overturning moment coefficient, K_m:

Mach No.	K_m
.4	.58
.6	.60
.8	.62

where the sound velocity was taken equal to the sound velocity in water, viz., 4600 ft./sec.

Computed value of $(K_m \rho d^3/B)^{1/2}$:

Mach No.	$(K_m \rho d^3/B)^{1/2}$
.4	1.06 inch^{-1}
.6	1.08 " "
.8	1.10 " "

where ρg = 270 grains/inch^3 for gelatin.

This bullet was designed to be fired at a muzzle velocity of 3950 ft/sec. from a rifle having a twist of one turn in 14 inches.

---

*Estimated by H. P. Hitchcock.

The target was a block of gelatin made by mixing 20 parts, by weight, of gelatin powder with 80 parts of water. The temperature of the gelatin target was kept at 50°F. Its dimensions were 5" x 6" x 15" with the 15" length parallel to the initial trajectory. The target was located approximately 20 yards from the muzzle.

EXPERIMENTAL PROCEDURE

On each round, the bullet velocity was measured by means of two foil screen pickups spaced 5 feet apart. The powder charge and twist of rifling were selected to simulate striking velocity and spin rate at ranges of 75, 250 or 450 yards. For the 250 yard simulated range, a rifle with the desired twist of one turn in 12 inches was not available. At this simulated range, shots were fired from a rifle having a twist of e in 9.7 inches thereby overspinning the bullet; another group was fired from a rifle having the twist of one in 14 inches in which case the spin rate was too low. Thus the desired spin rate was bracketed although the spin rate is, theoretically[3], supposed to have little influence on the yaw capabilities of the bullet.

The penetration by the bullet and the temporary cavity in the gelatin were observed at discrete times by means of a Fastax high-speed motion picture camera located on a line through the target and normal to the initial trajectory. Vertical wires spaced an inch apart provided reference lines. Floodlights were used to backlight the target. When the Fastax camera film was running at about 15,000 frames/sec., the shot was fired.

Although the bullet cannot be seen on the film, its path in the gelatin and the formation of the temporary cavity are visible. The distance to the center of the maximum temporary cavity and the dimensions of this cavity were measured on the film. The length of the initial straight path of the bullet in the gelatin target was also measured. Because the yaw angle is, theoretically, an exponentially increasing function of the distance penetrated, the departure of the projectile from its initial straight path is reasonably well defined; on the other hand, the measurement of the length of the initial straight path is somewhat arbitrary because the point where the path will no longer be considered straight cannot be specified exactly. The length of the initial straight path, therefore, was read to the nearest half inch.

Observations and measurements made from the gelatin target at rest after impact were as follows:

a. Whether or not the bullet was brought to rest in the gelatin target. An inert projectile which is stopped by the target transfers almost all its kinetic energy into strain energy of the bullet and target. It should do more damage to the target than it would if it passed completely through the target.

b. Whether or not the projectile shattered in the target. A shattering bullet might be considered a violation of the spirit of the Hague convention.[5]

c. The length of the longest radial crack in the gelatin measured perpendicular to the path of the bullet. In general, there are several cracks extending radially from the trajectory. These cracks represent a part of the permanent target damage. (The remaining permanent target damage lies along the trajectory in the boundary layer wherein viscous flow took place). The angles between cracks are seldom equal. The length of the cracks in the radial direction are unequal at a given coordinate. Between coordinates along the trajectory the length varies. The maximum length occurs, of course, near or at the trajectory coordinate corresponding to the center of the maximum temporary cavity.

RESULTS AND DISCUSSION

The results are given in Tables I, II and III. They are discussed below:

75 Yard Simulated Range

In Table I, it is stated that the projectile shattered on all rounds at this range. Therefore, the bullet may be declared unsuitable. It would be advisable to strengthen it or to reduce its muzzle velocity.

Because the bullet shattered, the measurements of the distance to the center of the maximum cavity may not be an accurate representation of the same distance which would be observed if the bullet remained intact. Also, the measurements of the longest radial crack and of the volume of the maximum temporary cavity may be different for the intact bullet.

250 Yard Simulated Range

From Table II, Part A, it can be seen that the projectile remained intact at the 250 yard simulated range. It traveled initially 2.5" to 4.5" through the gelatin on a straight line and then followed a curved path. The maximum cavity occurred 3.5" to 7.0" from the impacted face and the maximum permanent damage in the transverse direction extended out to 3.4" from the path. Although the projectile perforated the target on 90 percent of the rounds, its exit velocity was low as inferred from its shallow penetration into backstop material behind the target; it is estimated that the projectile transferred at least 90 percent of its striking energy to the target.

The mean distance to the center of the maximum temporary cavity for those bullets which were fired from a rifle having a twist of one turn in 9.7" is significantly greater than the mean distance for the one in 14" firings. This result implies that either the spin rate affects the distance to the center of the maximum temporary cavity, D, or, that the initial yaw angle of the bullet on impact, δ_o, was different, on the average, on rounds 26-30 than it was on rounds 31-35. To investigate these two possibilities, the experiments were repeated but with measurements of δ_o included. The additional results are given in Table II, Part B and are plotted on Figire 1. In the table, it is seen that the average value of δ_o for the bullets with the higher spin rate (twist = 1 in 9.7") was smaller than the average value of δ_o for the other bullets. From the figure it is seen that the same line can be used to represent both the circled points considered separately and the triangular points considered separately. It is concluded that the spin rate had no noticeable effect on D. And it follows that the difference in the average value of D, observed by the use of different twists of rifling, was caused by the difference in the average values of δ_o.

For the 50 grain experimental bullet the function $D(\delta_o)$ can be approximated by the equation

$$D = 7.6 - 1.2\delta_o \quad , \quad 0 \leq \delta_o \leq 2.6^o \qquad (1)$$

where D and δ_o are measured in inches and degrees, respectively. After $D(\delta_o)$ is determined, the mean value of D at all real ranges can easily be found. This statement is true provided the yaw angle as a function of the real range is known*. For example, at a real range of 250 yards or more the yaw angle of the 50-grain experimental bullet should be close to zero degrees and the estimated average value of D from (1) is 7.6". Then the problem of determining D for an experimental bullet is solved by determining $D(\delta_o)$ over the δ_o interval of interest.

Experimental values of the length of the initial straight path, L, are plotted on Figure 2. Because the value of D is about 1.6 times the value of L, statements similar to those just made for D also are true for L.

450 Yard Simulated Range

At the 450 yard simulated range the projectile was intact and passed out of the target through one of the side faces. Values of the longest radial crack and volume of the maximum temporary cavity were, on the average, lower than the values measured at the two shorter ranges; for each value a drop is expected because of the lower striking velocity at the 450 yard simulated range.

At a real range of 450 yards the yaw angle should be very small. Theoretically, the striking velocity has a negligible effect** on the values of D and L. Hence, at 450 yards real range the estimated value of D, from Figure 1, is 7.6" and the estimated value of L, from Figure 2, is 4.7".

Dependence of Cavity Volume on Striking Energy. In Figure 3, average observed values of the maximum temporary cavity volume, obtained from Tables I, II and III are plotted against the striking energy. The

* At real ranges the yaw angle is periodic, decreases in amplitude with range, and damps out to near zero far from the muzzle.

** Provided the value of K_m changes with velocity by a negligible amount; see Pg.6.

relationship is roughly approximated by a straight line whose slope has a value of 103 pounds/sq. inch. However, when real ranges are considered, it appears that this linear relationship needs to be modified. At real ranges, the value of δ_o is expected to be less than the values of δ_o which occurred for these experiments. The value of D at each real range should be greater than the value of D which was observed for each corresponding simulated range. From Table II, Part A, we see that the mean value of cavity volume decreased as the mean value of D increased. Then at real ranges the cavity volumes should be less than the cavity volumes indicated by the solid line of Figure 3. The estimated cavity volume for real ranges is given by the dotted line of Figure 3.

Longest Radial Crack. If we divide the mean cavity volumes given in Table I by the cube of the mean length of the largest radial crack, we obtain an essentially constant value of 5.4 for the 3000 ft/sec and 2000 ft/sec data; but at the highest striking velocity, the value of this ratio is 7.6. It is noted that the size of the target limited the extent of the crack at all but the lowest velocity level. Apparently, the limitation was most severe at the highest striking velocity. If this limitation were removed, it is reasonable to suppose that the value of 5.4 for the ratio would hold, approximately, at the 3600 ft./sec. velocity level. These observations strongly suggest that the present lateral dimensions of the target viz., 5" x 6", should be increased for future work with .22 cal. bullet at the 3600 ft./sec. velocity level.

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TABLE I

Simulated range = 75 yards
Striking Vel. = 3600 ft/sec
Twist = 1 in 14"

Rd. No.	Proj. Stopped by Target?	Condition of Proj.	Length of Initial Straight Path in Gelatin, inches	Distance to Center of Max. Cavity, inches	Longest Radial Crack (see note 2) inches	Volume of Max. Temp. Cavity, in^3
1	Yes	Shattered	S.C.	5.0	2.3	200
2	"	"	4.5	5.5	2.6	150
3	"	"		3.5		170
4	"	"	3.5	5.0		160
5	"	"	3.5	5.0		160
6	"	"	S.C.	5.0	3.0	190
7	"	"	S.C.	3.0	3.0	240
8	"	"	3.5	5.0	3.4	200
9	"	"	S.C.	7.0	2.8	160
10	"	"	S.C.	5.0	3.0	180
Average				4.9	2.9	180

Notes:

1. S.C. = small curvature of the trajectory.

2. The extent of maximum permanent damage to the gelatin target was limited by the cross sectional dimensions of the block, viz., 5" x 6". This is, the length of crack terminated at a boundary of the target.

3. The time interval between impact and the attainment of the maximum temporary cavity was 1.5 to 2.0 milliseconds.

TABLE II, PART A

Simulated range = 250 yards
Striking Vel. = 2900 to 3000 ft/sec

Rd. No.	Twist	Proj. Stopped by Target?	Condition of Proj.	Length of Initial Straight Path in Gelatin[3], inches	Distance to Center of Max. Cavity, inches	Longest Radial Crack (see note 2) inches	Volume of Max. Temp. Cavity, in^3
26	1 in 9.7"	No	intact[1]	4	6.5	2.8	85
27	"	"	"	4.5	7.0	2.5	65
28	"	"	"	4	5.5	2.2	105
29	"	"	"	4.5	6.5	2.8	105
30	"	"	"	4	5.5	2.7	115
Average				4.2	6.2	2.6	95
31	1 in 14"	Yes	intact[1]	3.5	5.5	3.4	125
32	"	No	intact	3	5.0	2.7	110
33	"	"	"	3.5	5.5	3.4	105
34	"	"	"	2.5	3.5	2.0	115
35	"	"	intact[1]	2.5	5.0	2.5	140
Average				3.0	4.9	2.8	120

Notes:

1. A few small pieces of the P_b core were squeezed out of the base.

2. The length of crack was terminated by a boundary of the target.

3. A typical path consists of a straight portion followed by a curved path.

4. On round 31 the projectile tumbled in the target. The final depth of penetration was 9.96".

TABLE II, PART B

Simulated range = 250 yards; actual range = 17 yards
Striking Vel. = 3000 ft/sec ± 75 ft/sec
Obliquity = 0°

Rd. No.	Twist of Rifling	Yaw Angle at Impact, degrees	Length of Initial Straight Path, inches	Distance to Center of Max. Cavity, inches
1S	1 in 9.7"	0.7	3.2	6.0
2S	"	1.0	4.0	7.0
3S	"	0.75	6.5	8.0
4S	"	0.8	4.0	6.2
5S	"	0.25	4.5	7.0
6S	"	0.0	3.5	6.5
7S	"	0.3	3.5	6.5
8S	"	0.0	5.8	8.5
9S	"	2.1	3.0	5.0
10S	"	1.8	3.5	6.2
Average	"	.77	4.2	6.7
11S	1 in 14"	2.0	2.5	5.0
12S	"	2.6	3.0	5.0
13S	"	1.4	2.8	5.0
14S	"	1.2	5.0	6.5
15S	"	0.0	4.8	7.3
16S	"	1.9	3.0	5.5
17S	"	2.3	3.5	5.5
Average	"	1.63	3.5	5.7

TABLE III

Simulated range = 450 yards
Striking vel. = 2000 ft/sec
Twist = 1 in 9.7"

Rd. No.	Proj. Stopped by Target?	Condition of Proj.	Length of Initial Straight Path in Gelatin inches	Distance to Center of Max. Cavity inches	Longest Radial Crack inches	Volume of Max. Temp. Cavity, in^3
11	No	intact	6.0	7.0	2.2	40
12	"	"	4.0	6.0	2.2	55
13	"	"	5.0	6.5	1.7	30
14	"	"	4.0	5.5	2.3	60
15	"	"	5.0	6.5	2.0	
Average			4.8	6.3	2.1	48

Notes:

1. All cracks in the target are internal.

2. The typical path consists of a straight portion followed by a curved path.

3. The time between impact and attainment of the maximum temporary cavity was about 1.5 milliseconds.

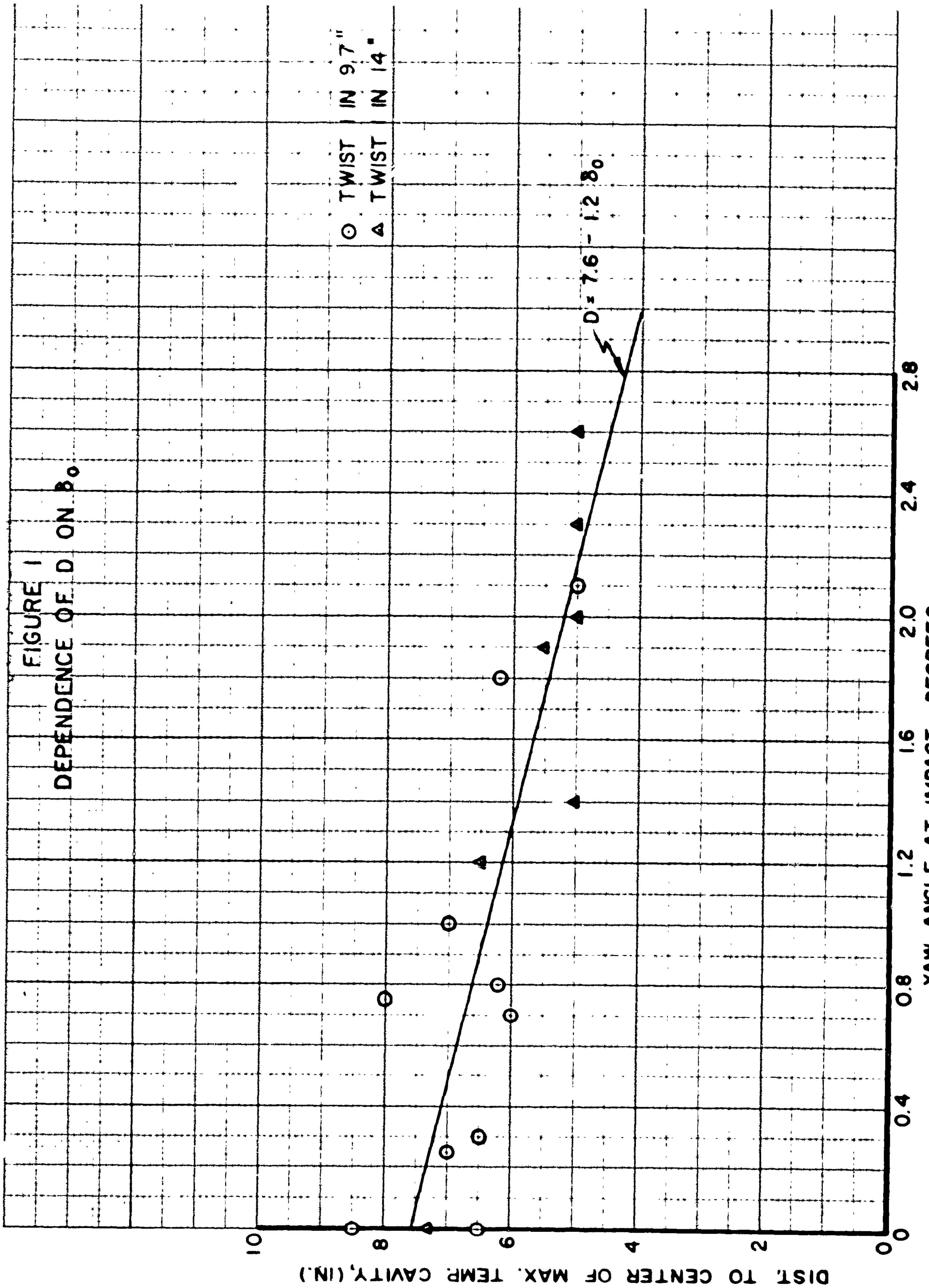

FIGURE 1
DEPENDENCE OF D ON δ_o

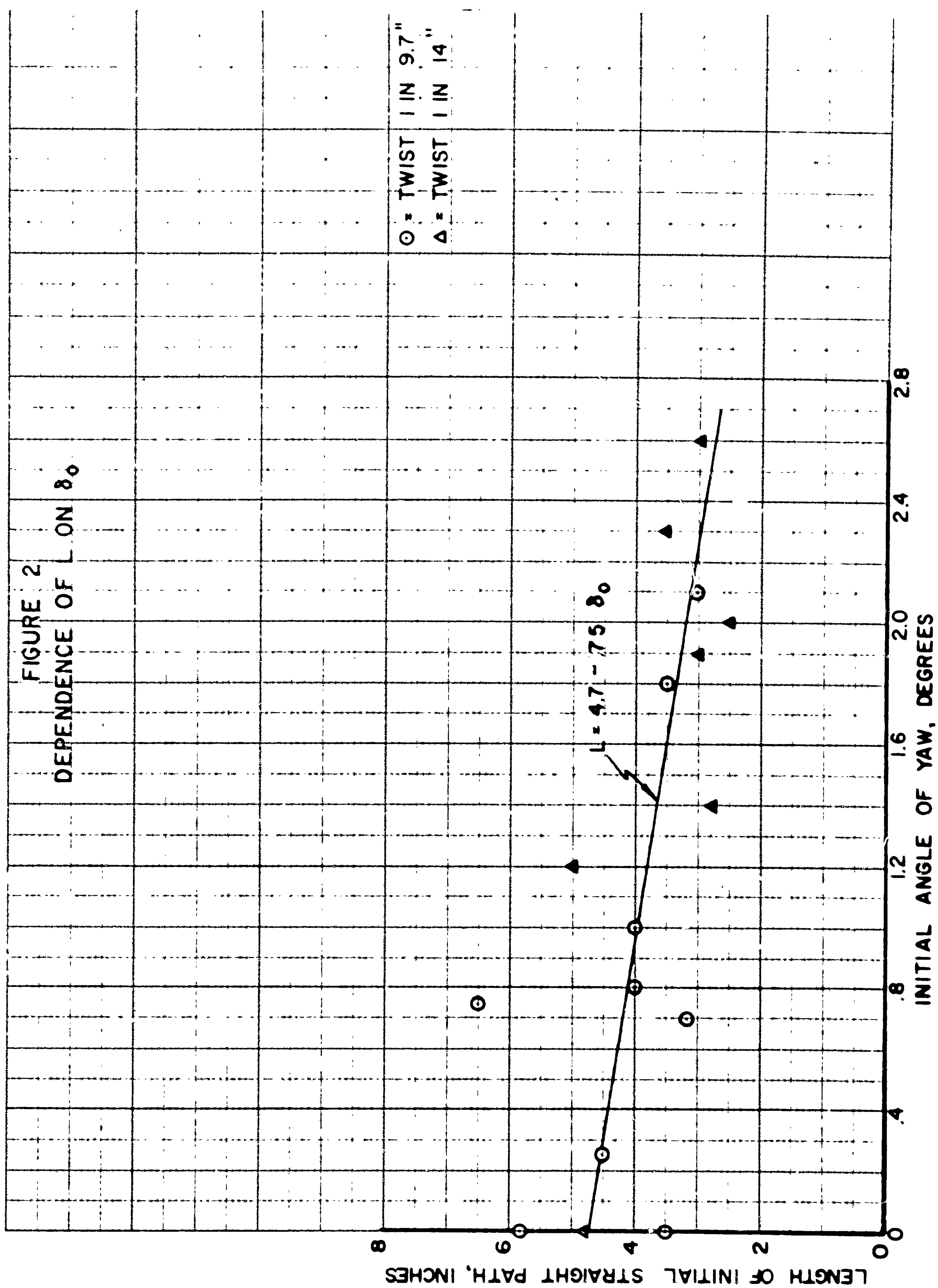

FIGURE 2
DEPENDENCE OF L ON δ_o

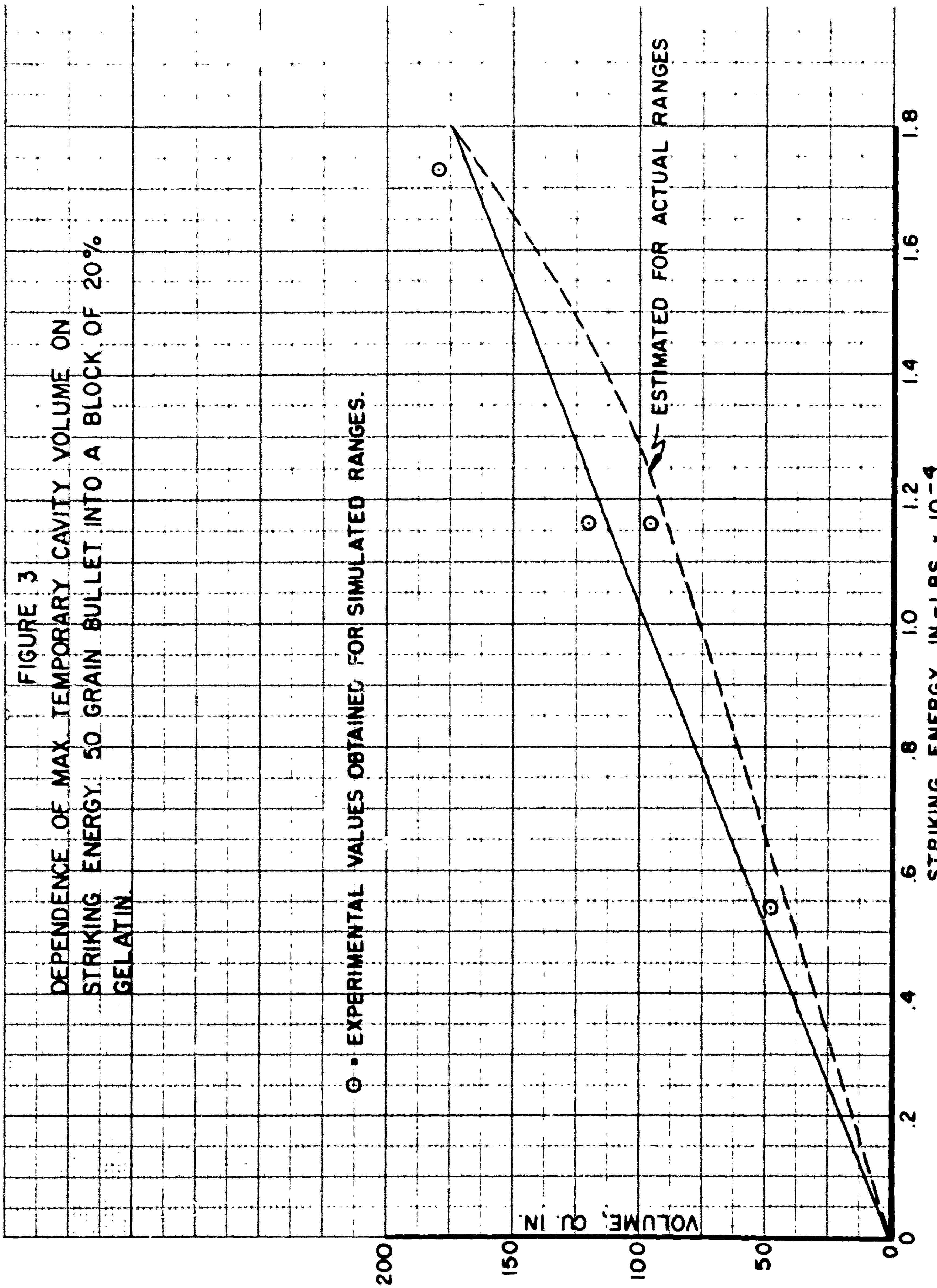
FIGURE 3
DEPENDENCE OF MAX. TEMPORARY CAVITY VOLUME ON STRIKING ENERGY. 50 GRAIN BULLET INTO A BLOCK OF 20% GELATIN.
⊙ = EXPERIMENTAL VALUES OBTAINED FOR SIMULATED RANGES.
ESTIMATED FOR ACTUAL RANGES
VOLUME, CU. IN.
0
50
100
150
200
STRIKING ENERGY, IN.-LBS. x 10^-4
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8

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